Beam instruments for high power spallation neutron source and facility for ADS

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J-PARC/JAEA: M. Ooi, H. Kinoshita, H. Takada, Y. Iwamoto

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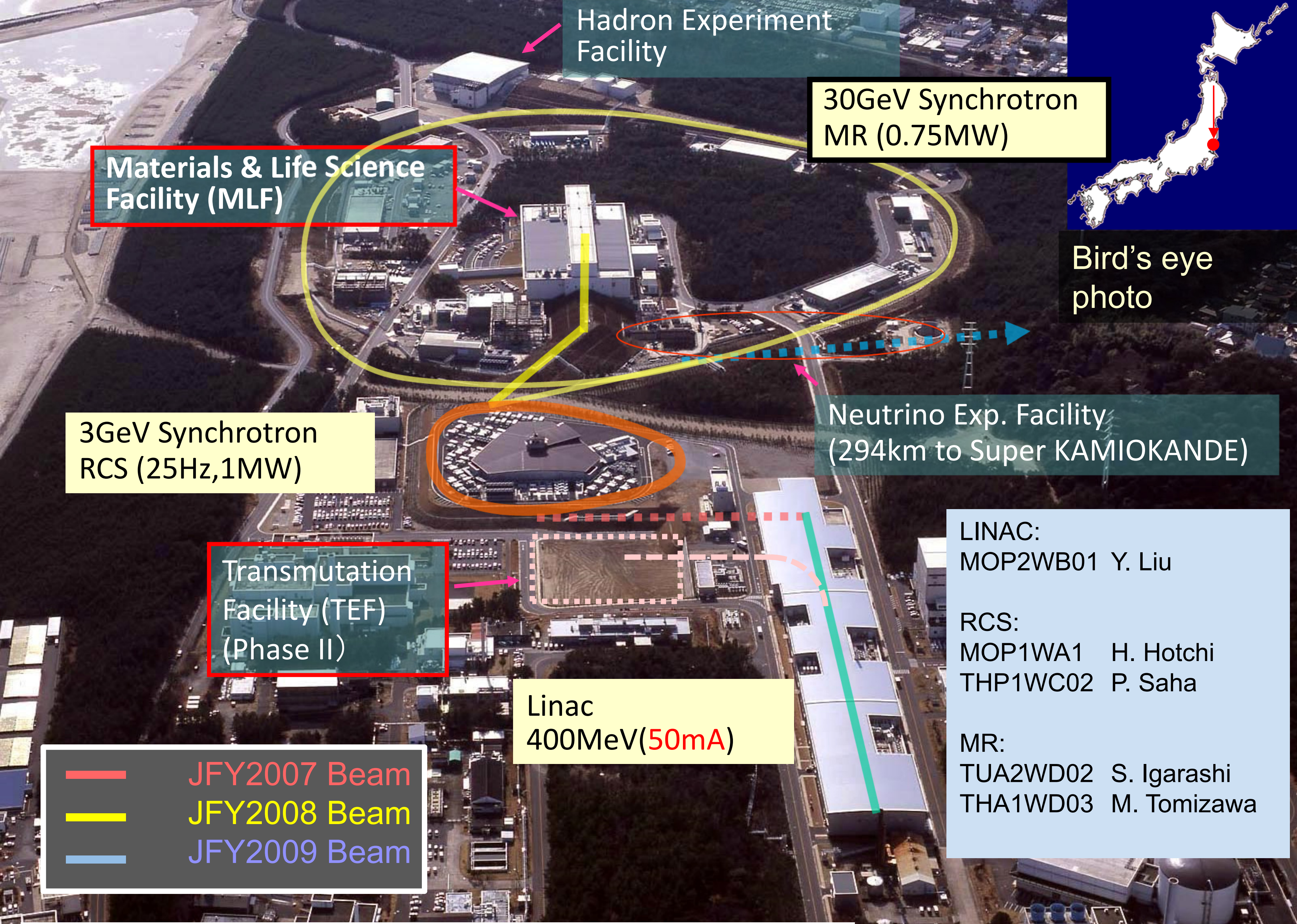
QST Takasaki: Y. Yuri, T. Yuyama

- Present study includes the results of “Measurement of displacement cross-section at J-PARC for structural material utilized at ADS” entrusted to JAEA by MEXT

Outline

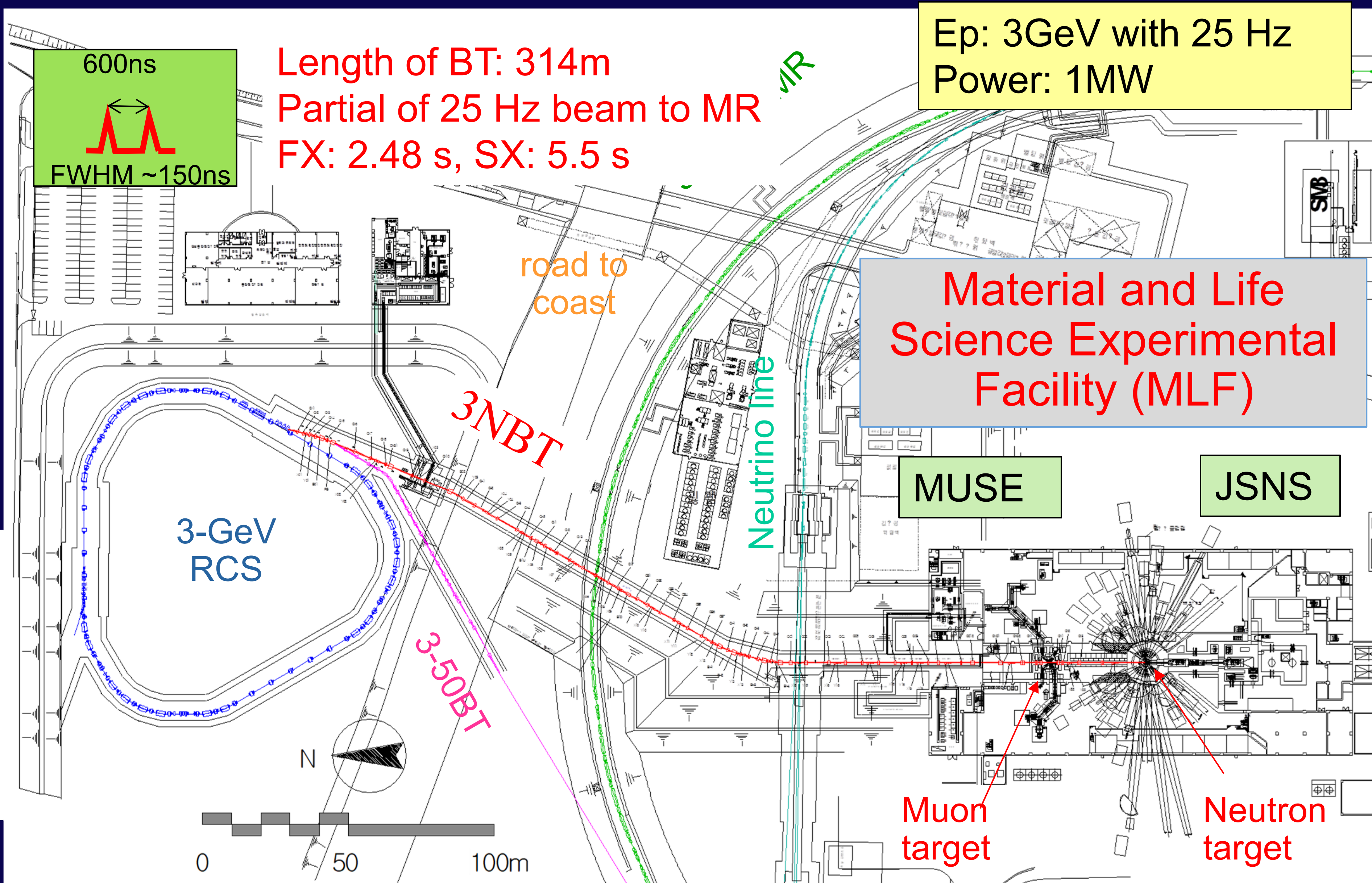
- Introduction
  - Present J-PARC Center status and future
  - Accelerator Driven System (ADS)
- Beam flattening system with nonlinear focusing
- Beam instrument R&D for future plan ADS
- Summary



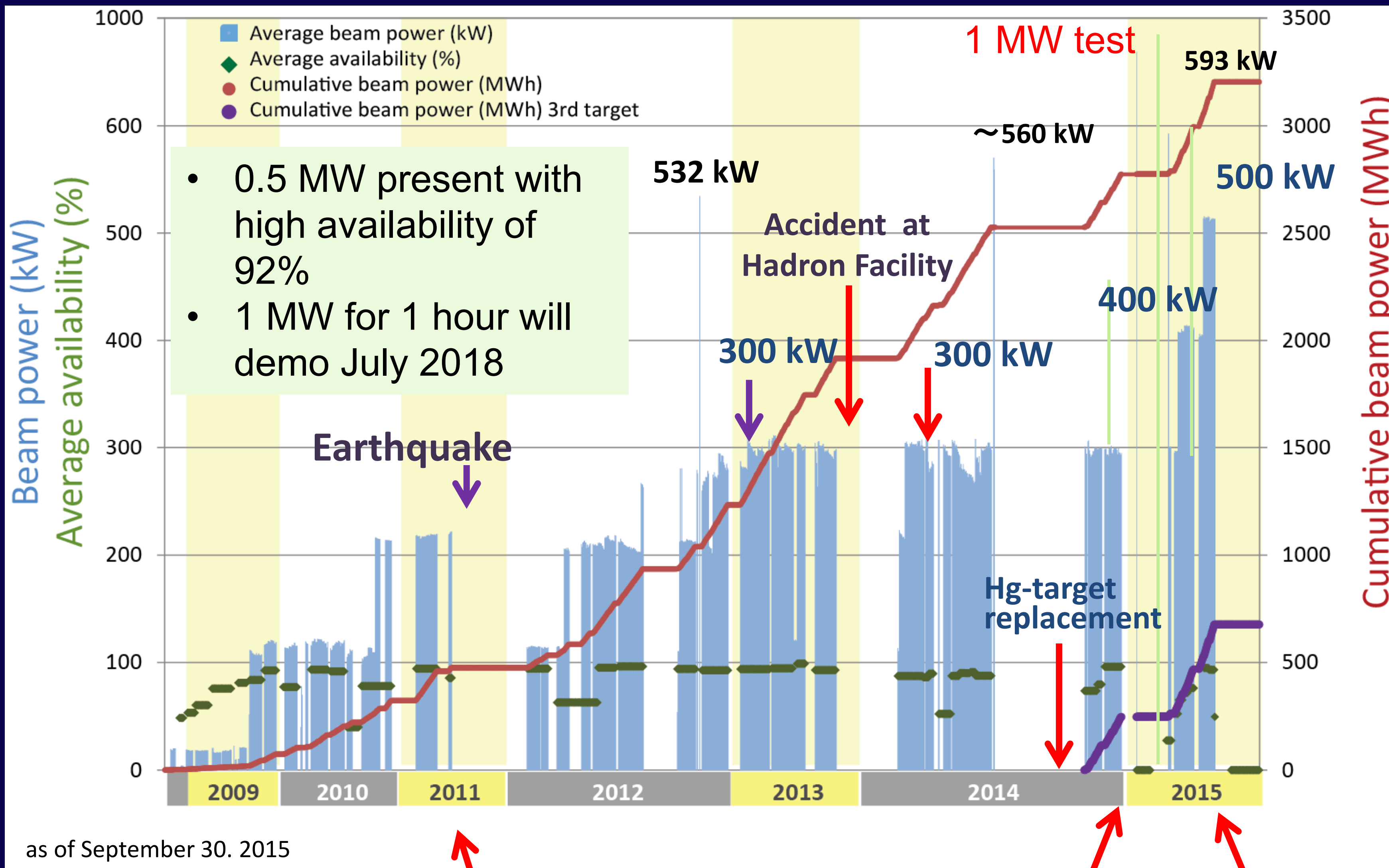
J-PARC = Japan Proton Accelerator Research Complex

MLF in J-PARC

600ns



Operational history of MLF



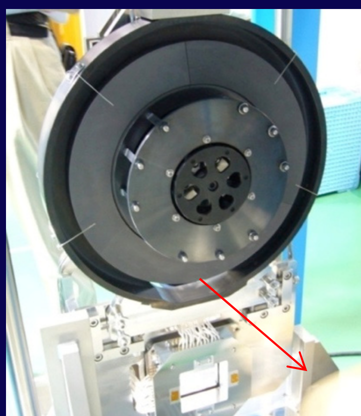
Hg-target replacement

~1 month interruption due to the fire in MLF

Interruption due to a trouble of Hg-target

Targets placed at MLF

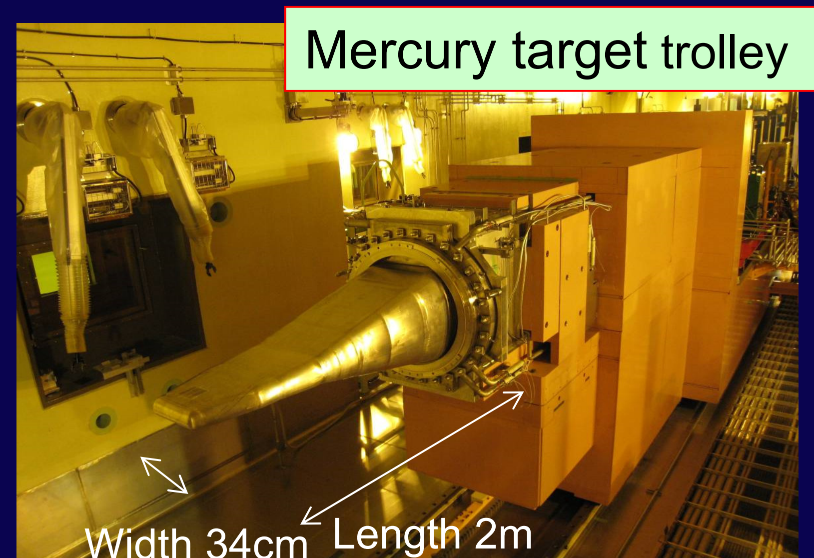
- Muon target
  - Carbon graphite (IG430)
  - 8% beam lost(80 kW loss)
  - Highest intensity in the world

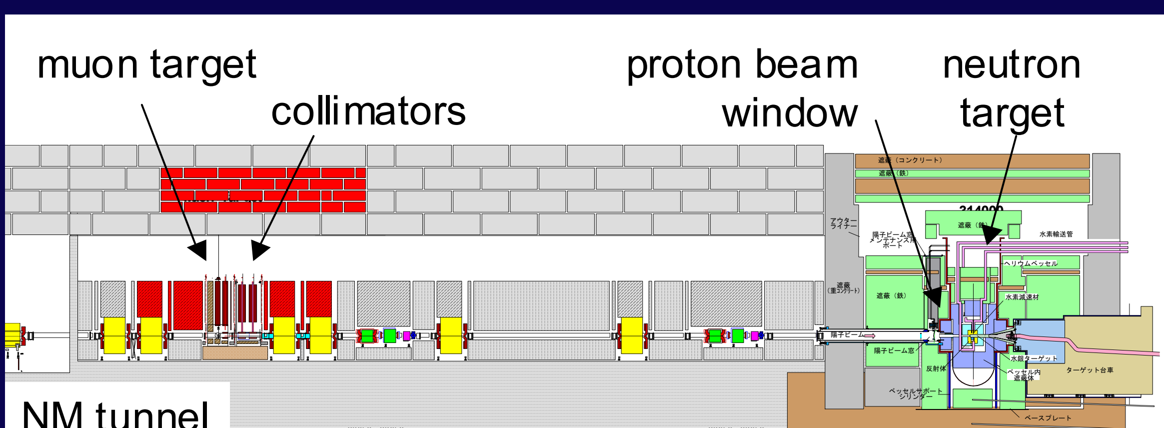


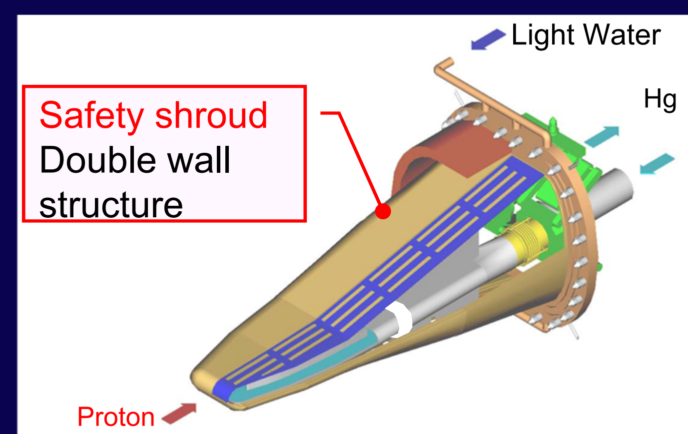
Rotating target

Thick. 2cm
Diam. 30 cm

- Neutron target
  - Mercury
  - Highest pulse intensity in the world







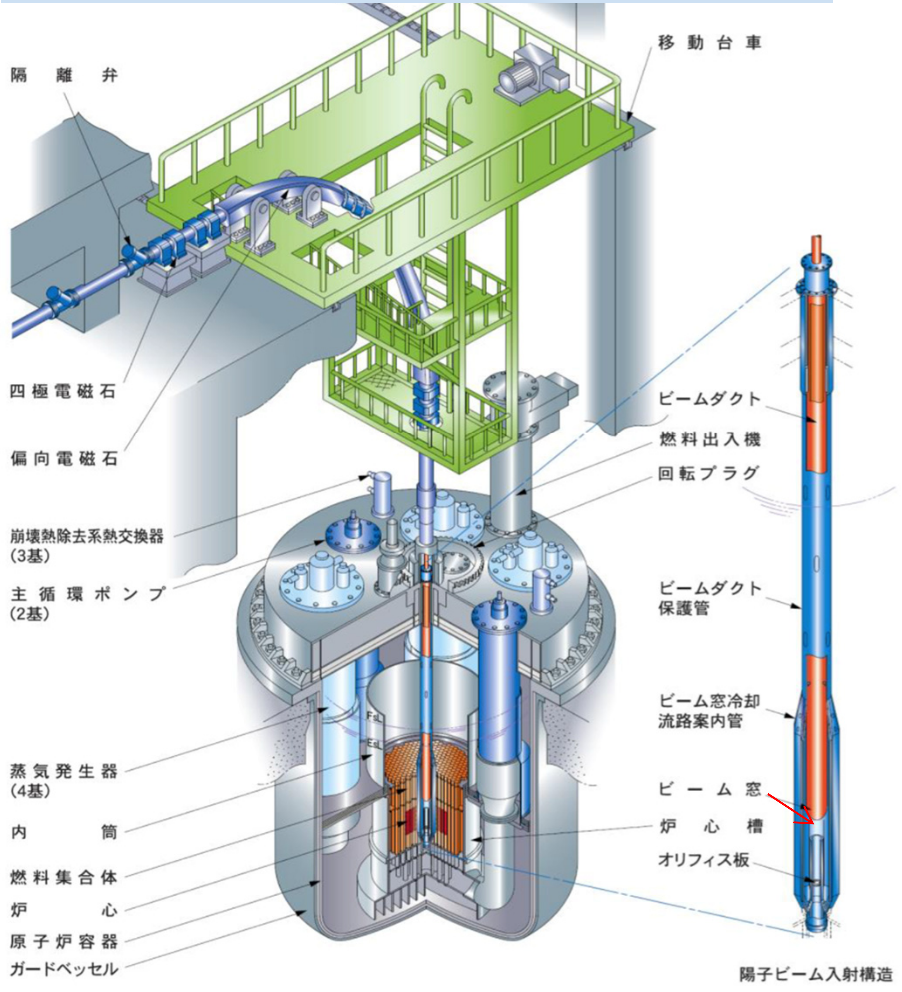
ADS Proposed by JAEA *- LBE Target/Cooled Concept -*

Many instruments will be deployed for safety.

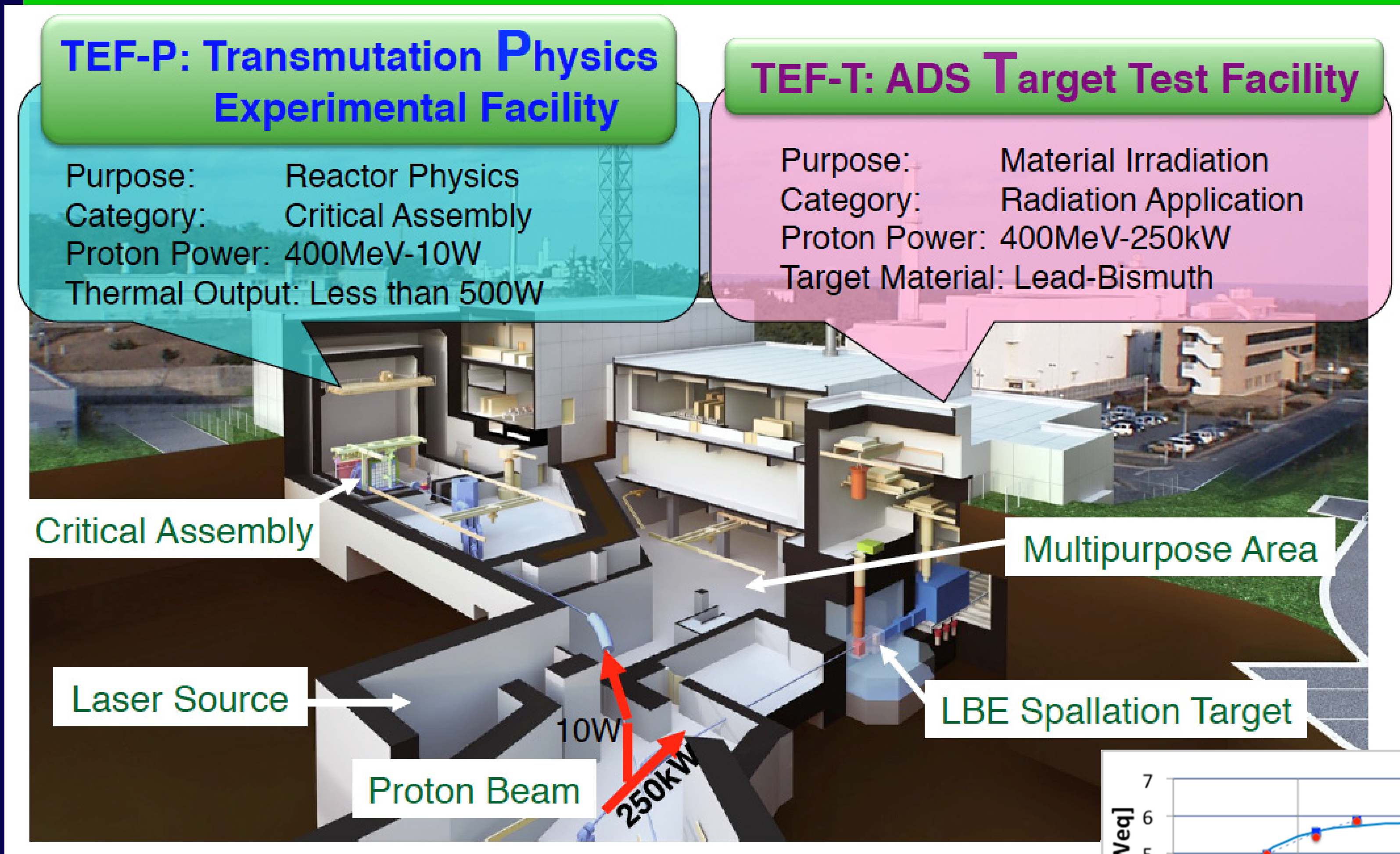
- Proton beam : 1.5GeV ~20MW ~ 30 MW
- Spallation target : Pb-Bi
- Coolant : Pb-Bi
- Subcriticality : $k_{eff} = 0.97$
- Thermal output : 800MWt
- Core height : 1,000mm
- MA initial inventory : 2.5t
- Fuel composition :

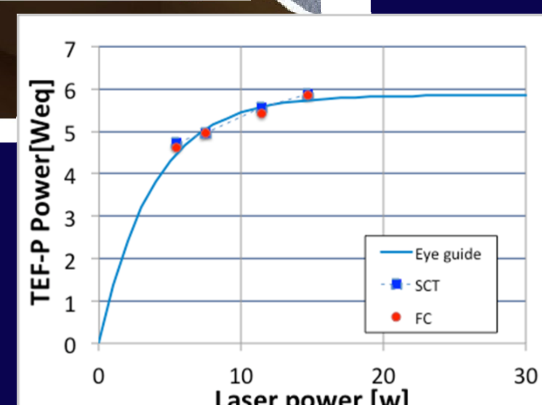
  (60%MA + 40%Pu) Mono-nitride
- Transmutation rate :

  10%MA / Year (**10 units of LWR**)
- Burn-up reactivity swing : 1.8%Δk/k



Transmutation Experimental Facility (TEF) in J-PARC

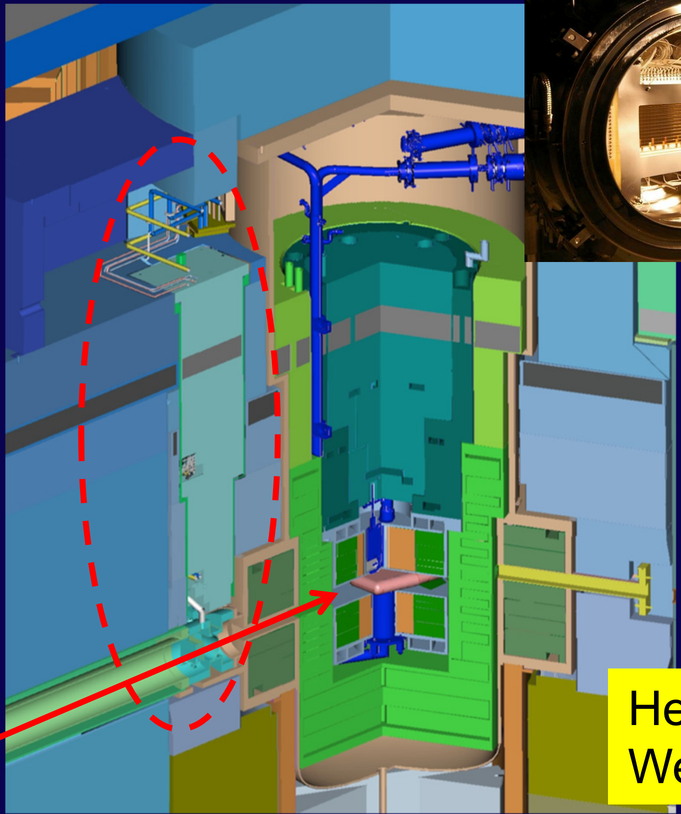


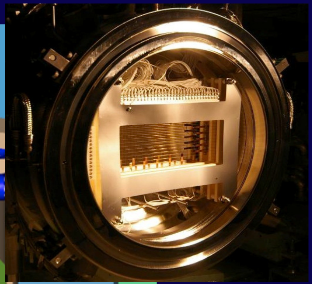


Result of beam separation test with Laser and 3-MeV H^- beam

Proton Beam Window

- Boundary between accelerator and target station
- Lifetime estimation based on Post Irradiation Examination (PIE) for safety shroud (aluminum alloy, AlMG3) at SINQ in PSI
- To predict lifetime of the PBW, high accuracy of calculation code is required.

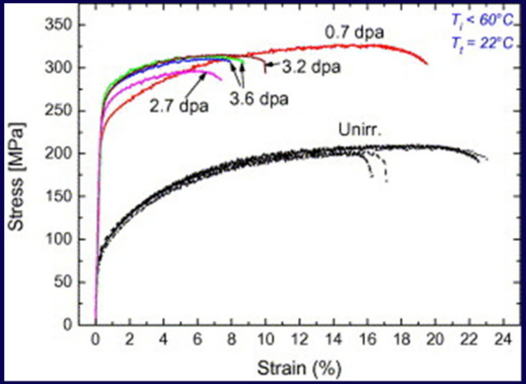


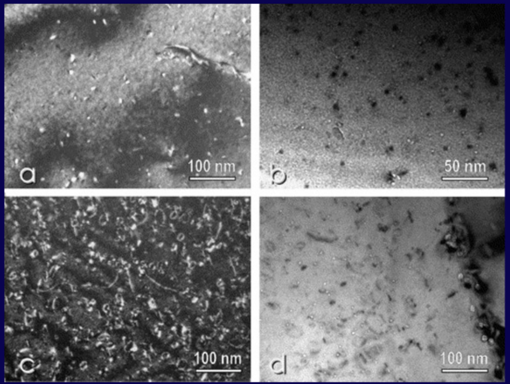


Height: 3.8m
Weight: 10t

Result at SINQ/PSI for 0.6GeV

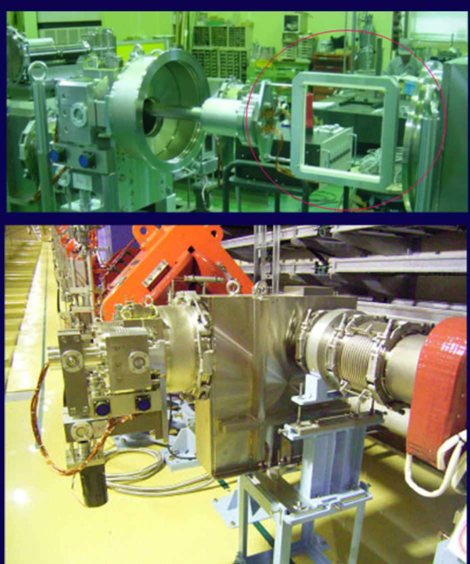
Y. Dai, et al, J. Nucl Mat. 343 184 (2005)



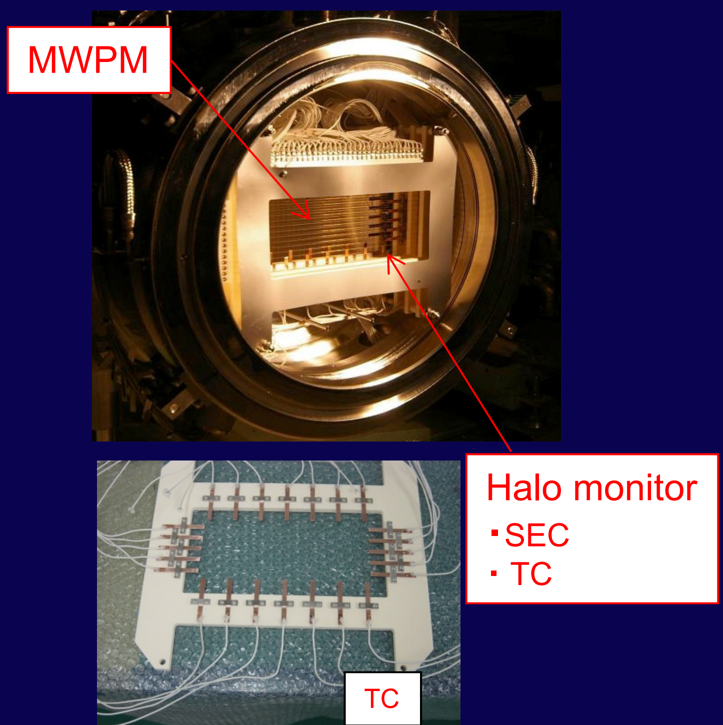


Beam profile and halo monitors

- Profile monitor and halo monitor (online monitor)
  - Multi Wire Profile Monitors (MWPMs) : SiC wires (15 sets)
  - Stationary MWPM at proton beam window (PBW), separation between vacuum and helium, placed at 1.8 m upstream of the mercury target
- 2D profile： Image of residual dose read out by imaging plate (IP)
  IP attached to target by remote handling after beam irradiation



MWPM



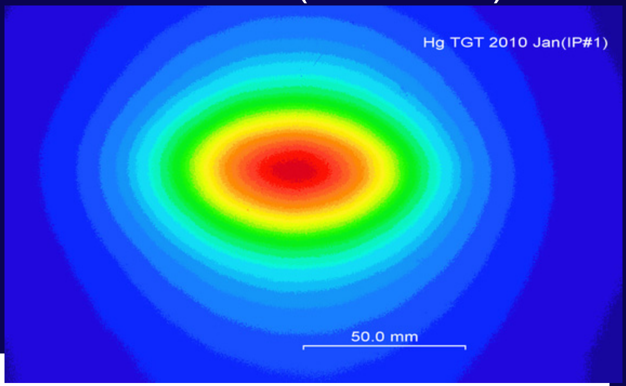
Monitors at PBW

Imaging Plate(IP)

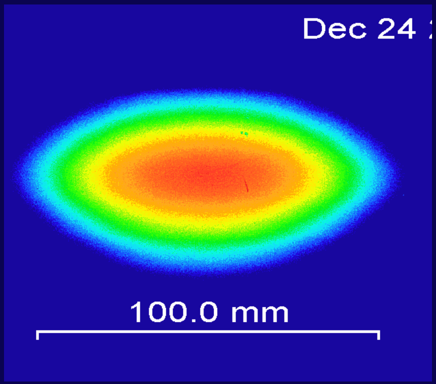
Beam profile at mercury target

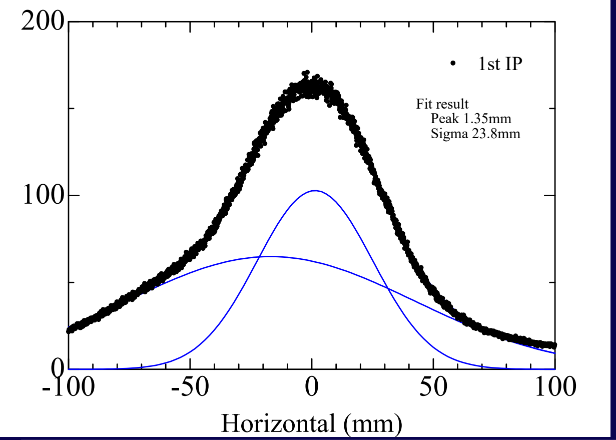
2-D measurement by IP

0.1 MW (2009 Dec)



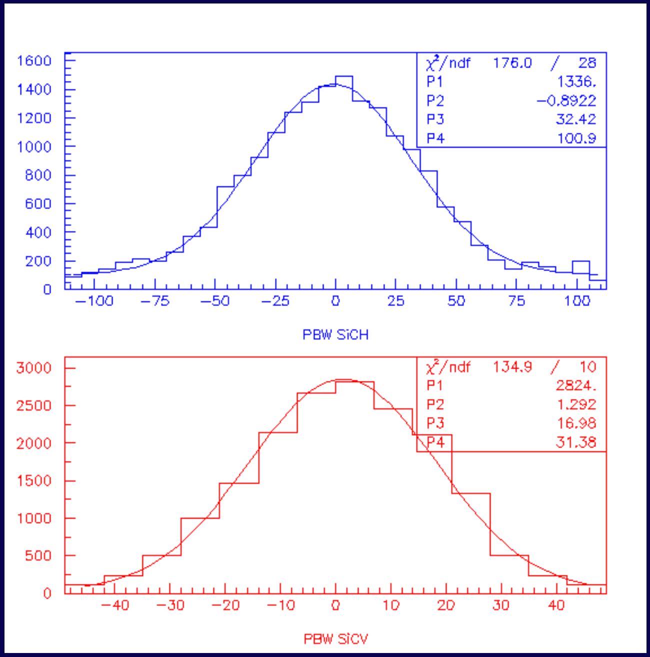
0.2 MW (2010 Dec)





Only 6 days cooling after irradiation of 0.2 MW beam, the image was obtained.
⇒ Possible for 1MW with certain cooling time

MWPM at PBW



Profile result by the IP

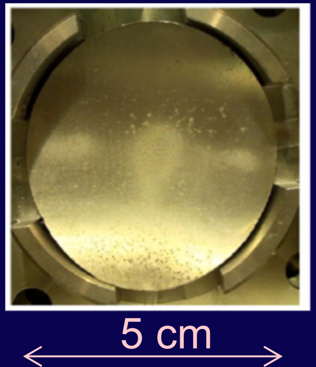
- Fitted by two Gaussian
  Convolution primary protons and secondary particles

MWPM result fitted by Gaussian

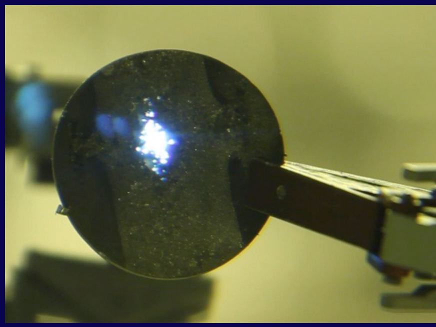
- Width and position for each pulse obtained
- Good agreement width result by IP
- Deployed Machine Protection System

Proton beam at the target

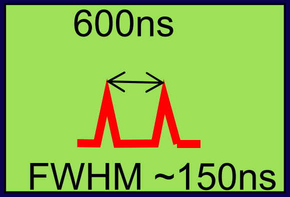
- Cavitation damage is critical for high power beam with short pulse
  - Proportional to 4^{th} power of the peak current density at target
  - Beam energy per shot at MLF is ~2 times of SNS.
  - Raster scanning is useless to mitigate damage.
- Although helium bubble injection to mercury mitigates the damage, peak reduction is essential.
- Required development of beam flattening system to mitigate peak density.

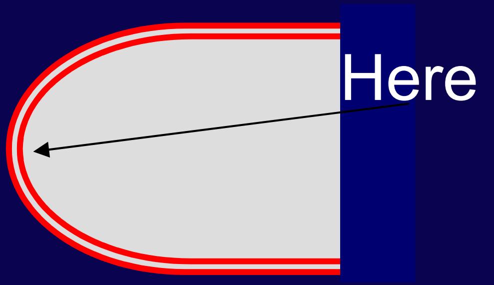


Damage at JSNS target



Pin holes at target of SNS (by B. Riemer)

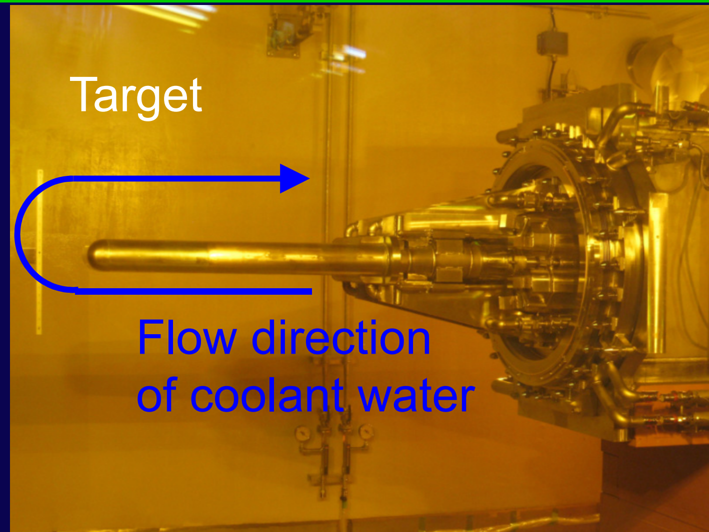


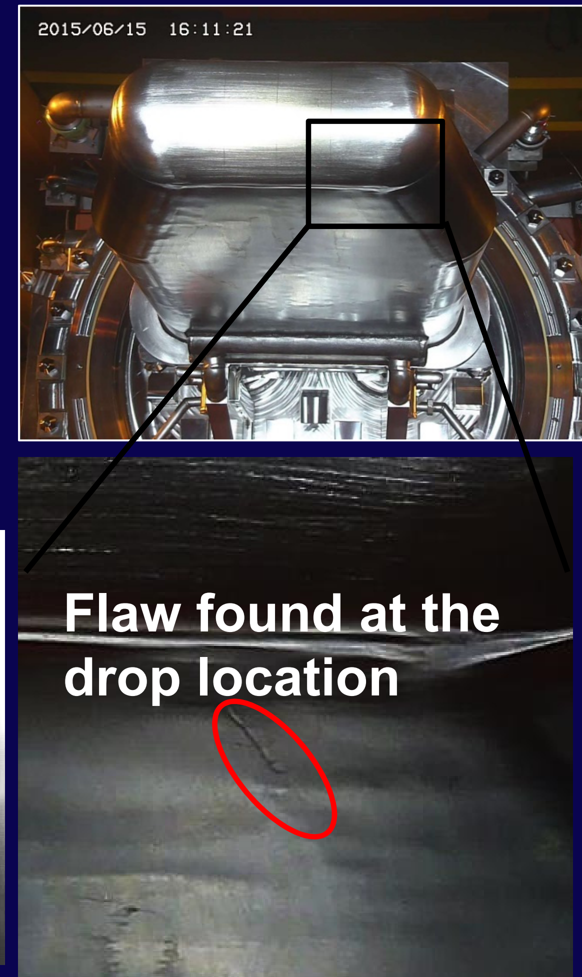


Target vessel

Inspection of mercury target failure

- Observation of target surface by a camera
- Pressurizing water shroud with gas (0.16 MPaG)
- A water drop found on the lower surface of the target





- Welding of shroud makes water leaks twice.
- The present target welding was inspected by X-ray before installation.
- To avoid damage welding, beam should be focused.
- For achievement contradict requirement, beam shaping with nonlinear is important.

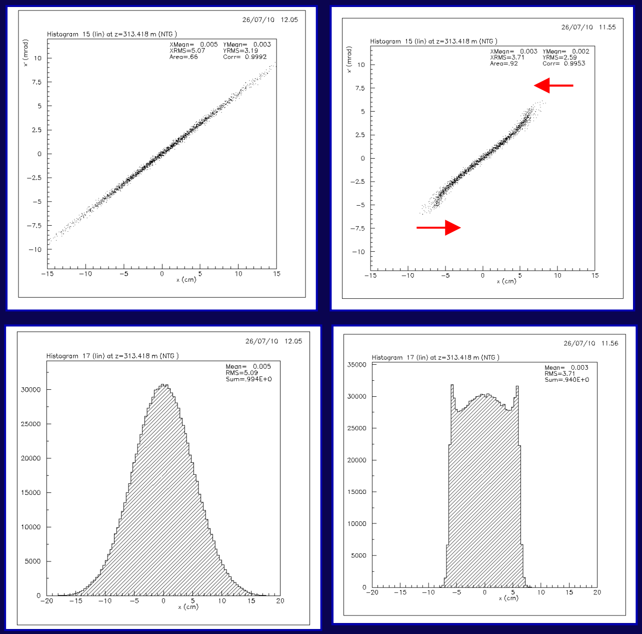
Beam shaping system with nonlinear focusing

- Principle: Beam edge folded by non-linear optics

Linear | Non-linear

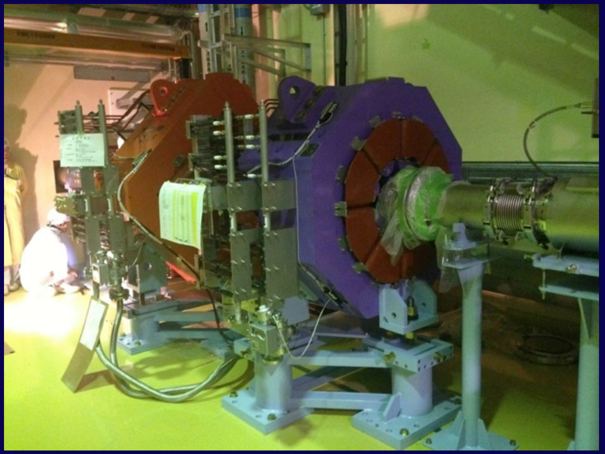
Phase space — Divergence

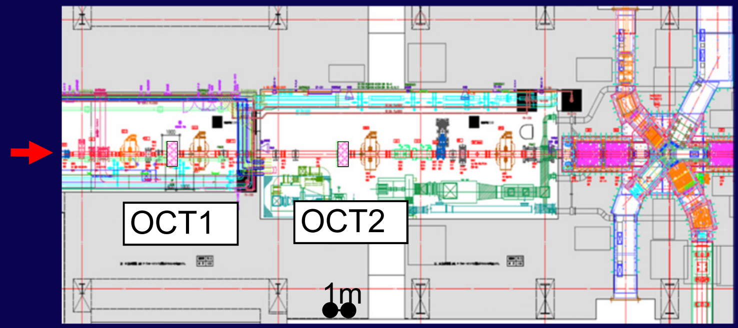
Real space (Horizontal) — Intensity



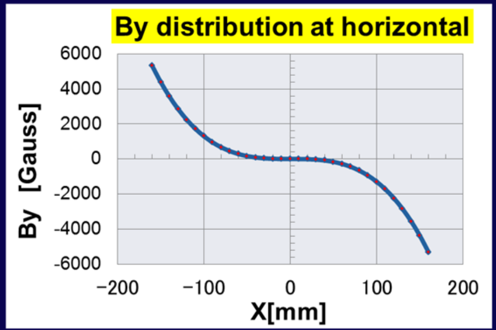
Position | Position

Octupole magnet: 800 T/m^3





Horizontal plan

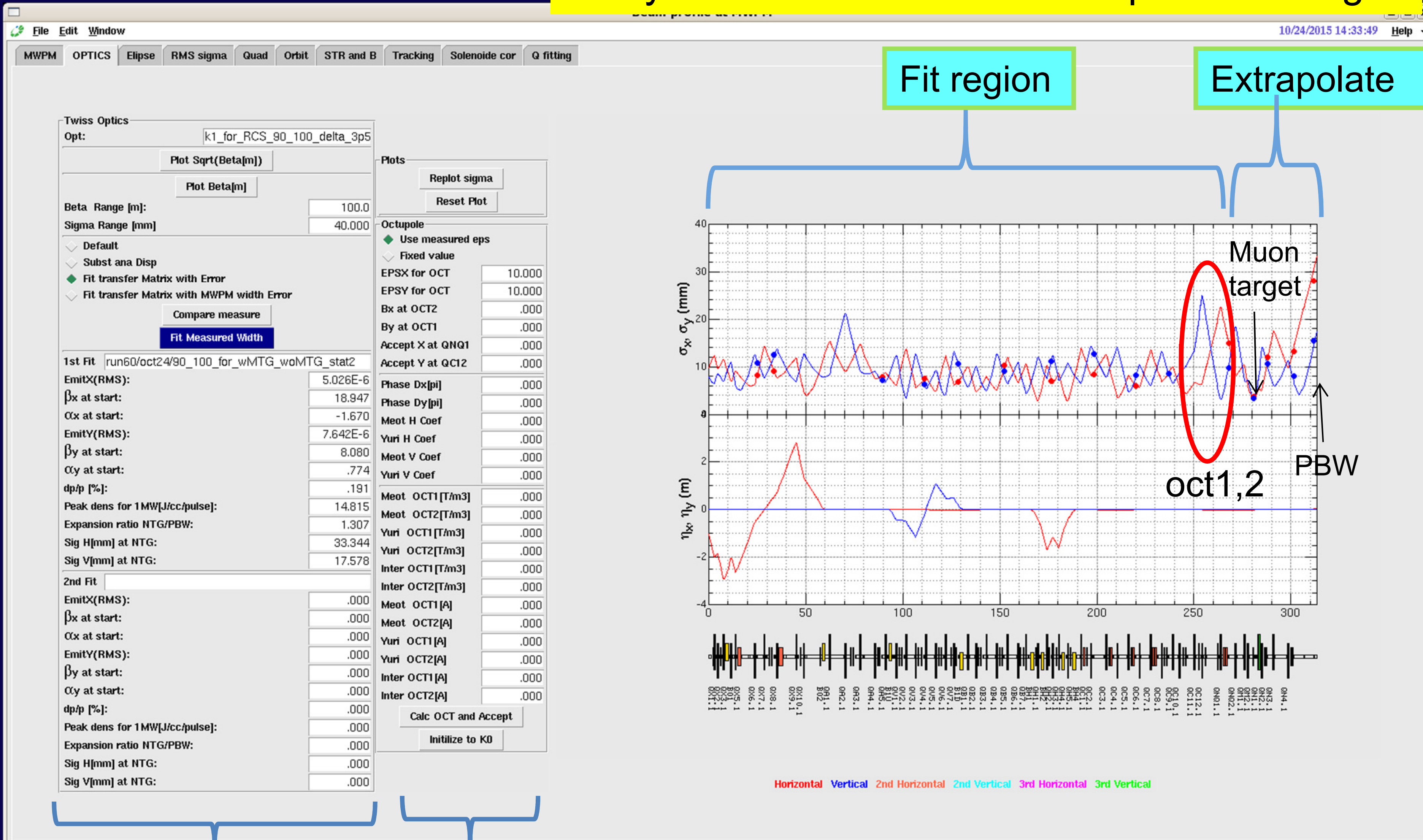


3rd order field beam folds to center.

Beam tuning tool with SAD code

$T = R^{-1}M$

Fit by observed width and extrapolate to target



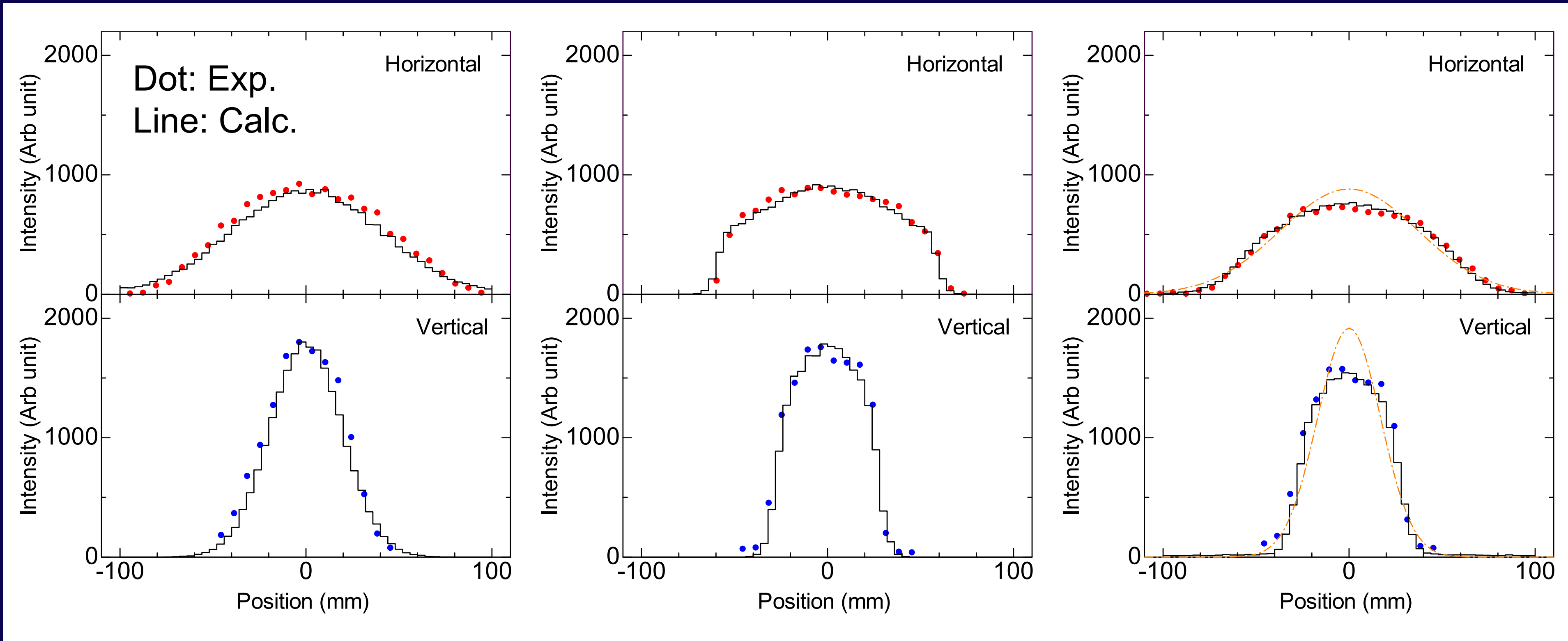
Fitted parameter OCT tuning Beam profile can be estimated by tracking

Obtained beam profile

OCT 0A

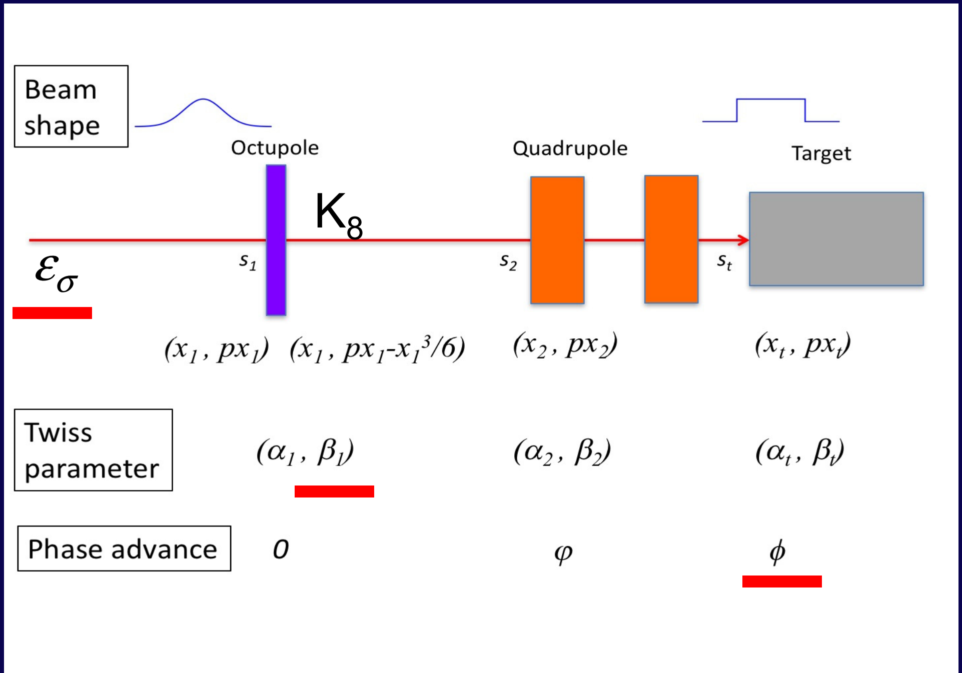
OCT 698A

OCT 698A
with muon target

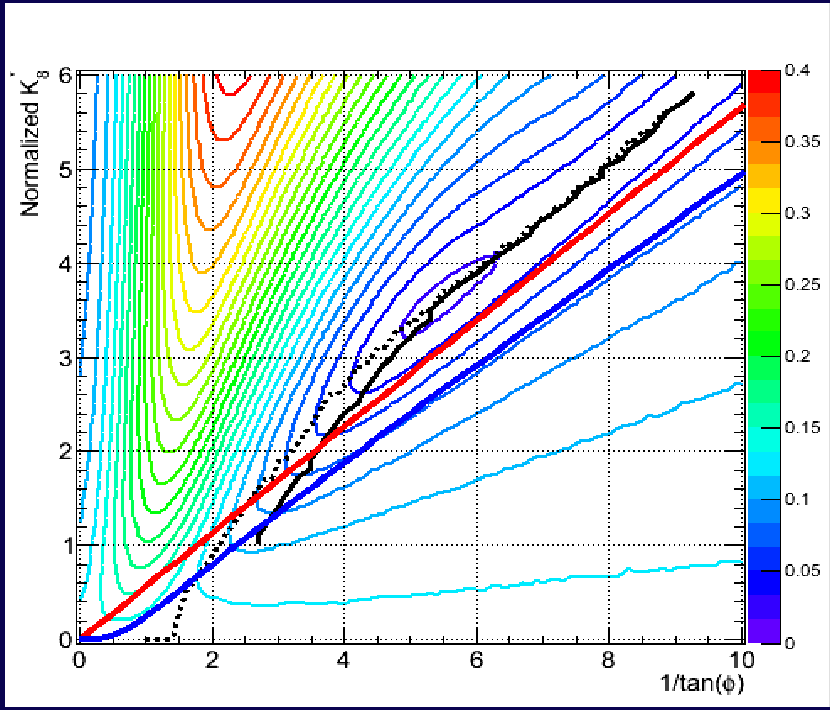


- Flat beam was obtained and lower intensity at edge was observed
- Good agreement of calculation even for with muon target
- Peak intensity (6 μA/cm^2) decreased by 30~40 % than that of linear optics.

Nonlinear optics tuning



- Flatness RMS within $\pm(\varepsilon\beta)^{0.5}$ (i.e. $\pm 1\sigma$ for linear optics)



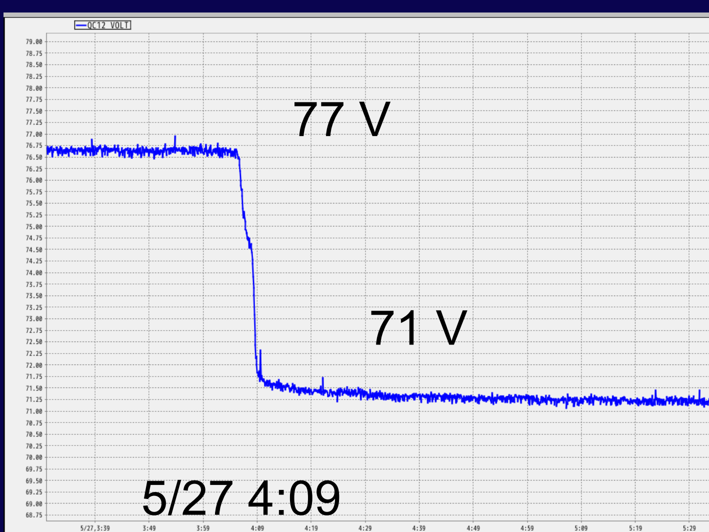
To generalize, the following normalized strength is introduced.

$$K_8^* \equiv 9\pi K_8 \varepsilon_\sigma \beta_1^2 / 16$$

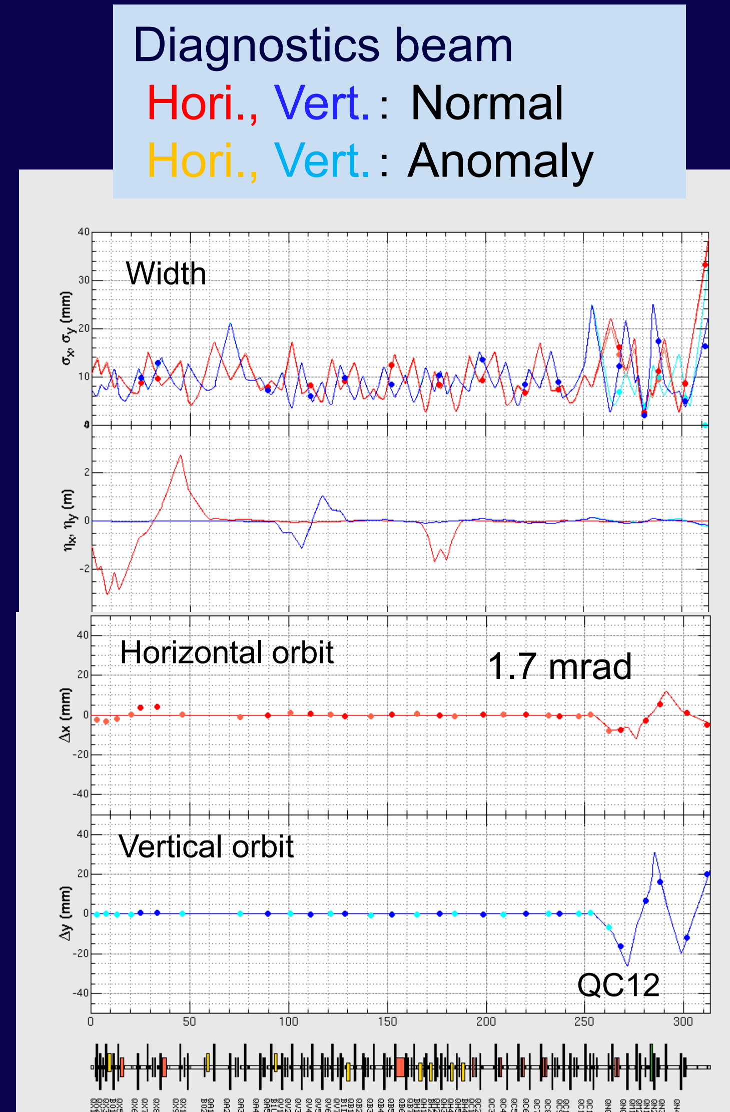
- For mitigation beam loss, lower K_8 is employed.
- Around tan ϕ~0 beam loss enhanced.
- Both raster scan and nonlinear will be preferable for ADS to minimize damage window.

Layer short circuit at a quad mag

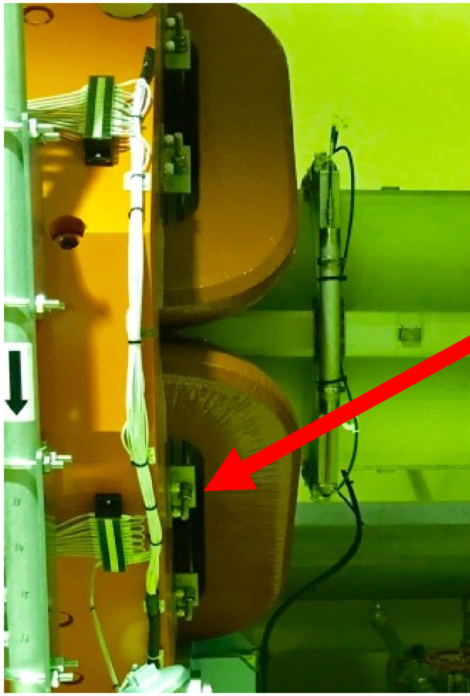
- 4 AM on May 27 2018, beam position distorted about 20 mm at the target.
- Soon, the halo monitor stopped the beam by the Machine Protection System (MPS).
- We found out the reason of distortion cause by layer short of a quadrupole magnet.

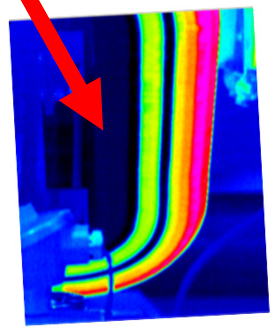


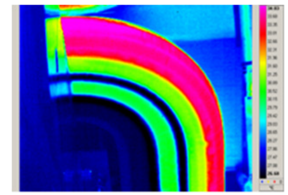
- BM at MR had layer short

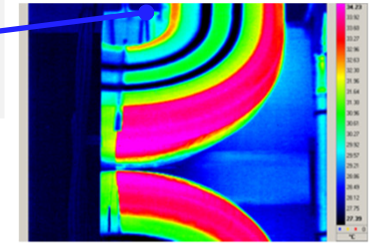


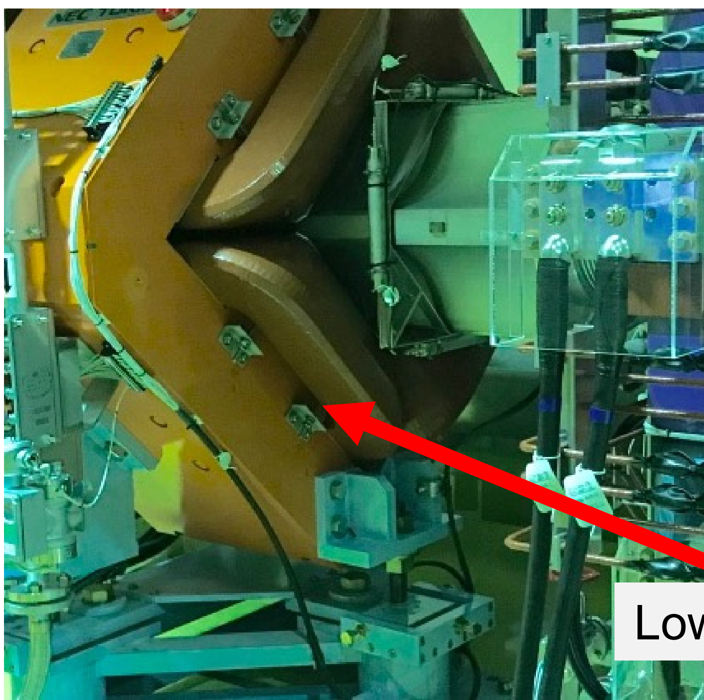
ThermoView observation of QC12

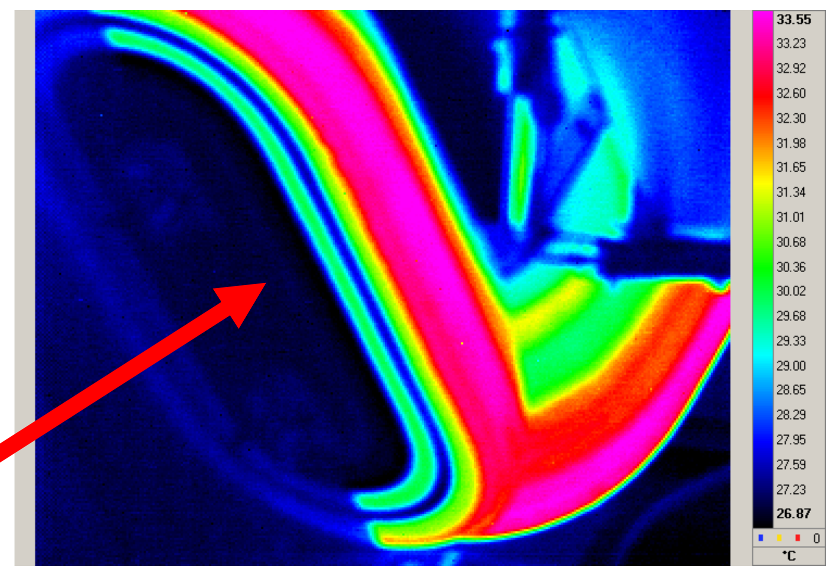




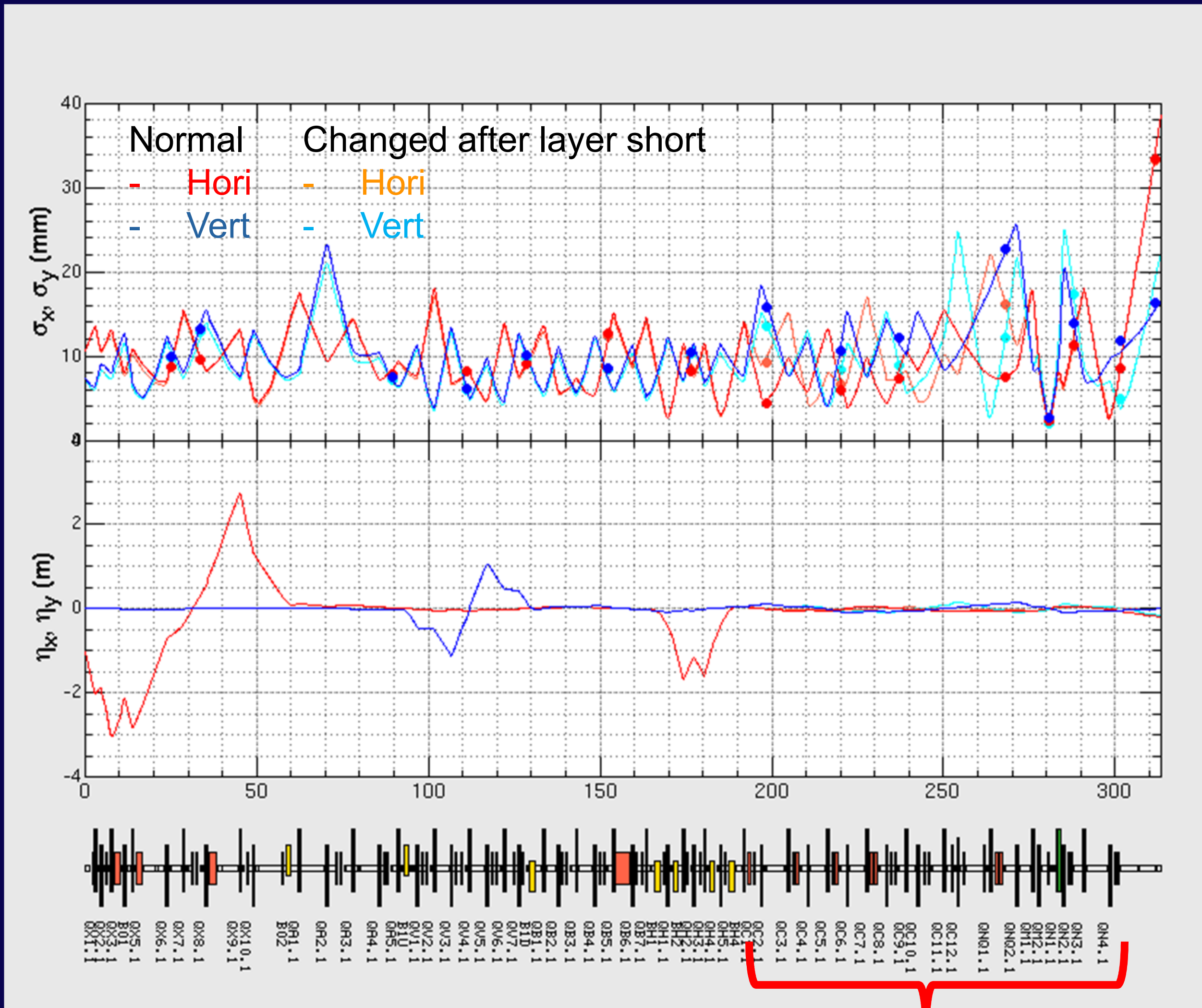








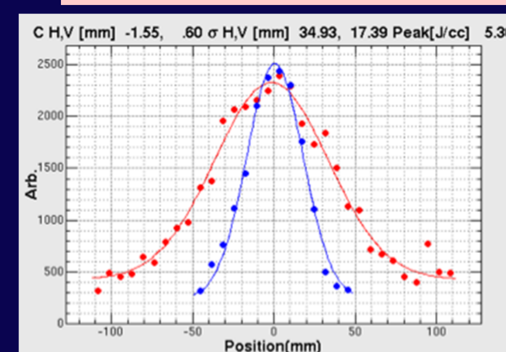
Optics recovery layer short



Drastically changed without QC12

- Even though having a back up coil, 7 days break to fix up.
- It was decided to not use QC12.
- Due to good quality of the beam, beam can be delivered with no significant loss.
- Linear optics applied because of difficulty of nonlinear optics

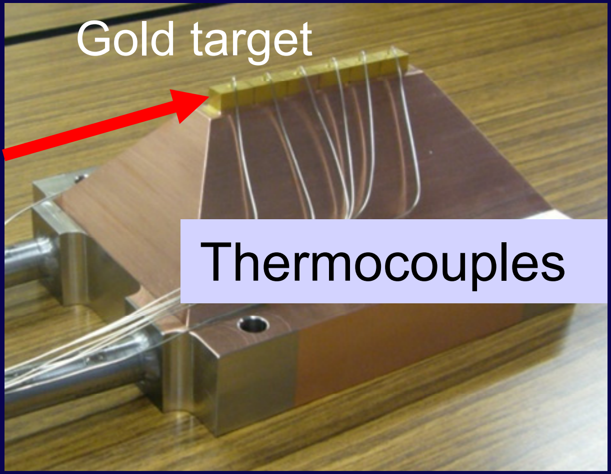
Beam profile without QC12



Lesson and learn

- Failure comes when we forget.
  - Eventually, a tiny failure such as layer short drastically improves the safety.
- We should improve redundancy against beam anomaly.
  - Beam position distortion
    - Many thermocouples implemented to MPS
  - Anomaly for beam density
    - Existing only one system of beam profile and preferable increase redundancy
    - Thermocouple will be installed at center of target or will be installed additional profile monitor.

Hadron target

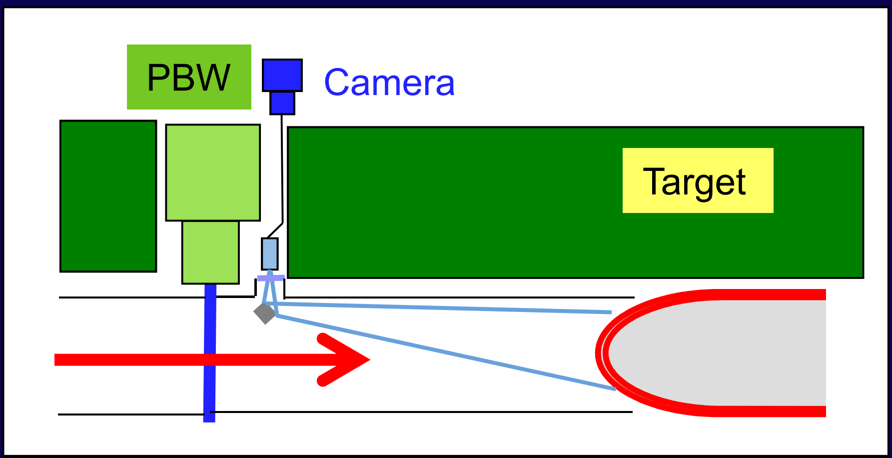


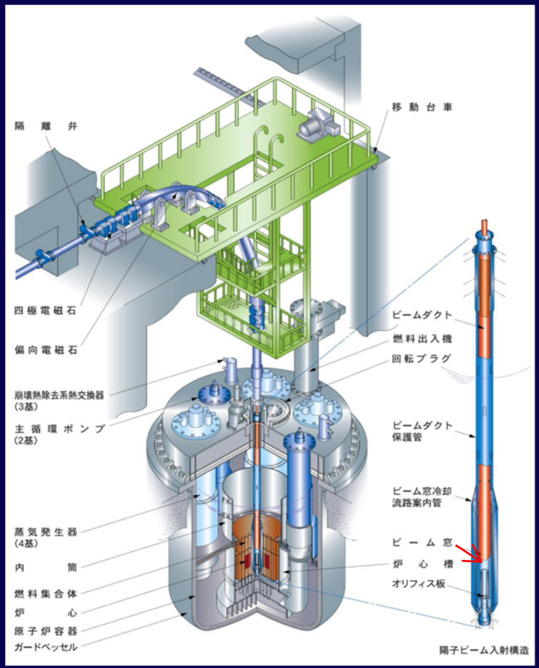
- When TC failed, the beam operation to MLF is thought to be stopped for long time.
- To understand robustness of TC, it is better to place TC at the center of mercury target in MLF, which also plays anomaly beam detector.

Development new profile monitor

A new profile monitor required to continuously observe 2D profile withstanding high power beam

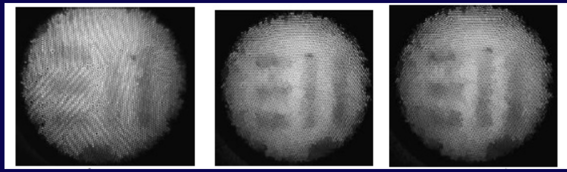
- Rad hard fiber scope (Fujikura FIGR-20, 2x10^4 pixels) coupled with near-IR filter
- Suitable for ADS





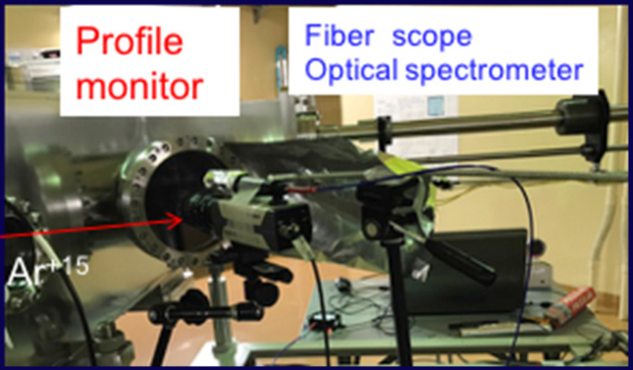
Heater test

Fujikura Fiber



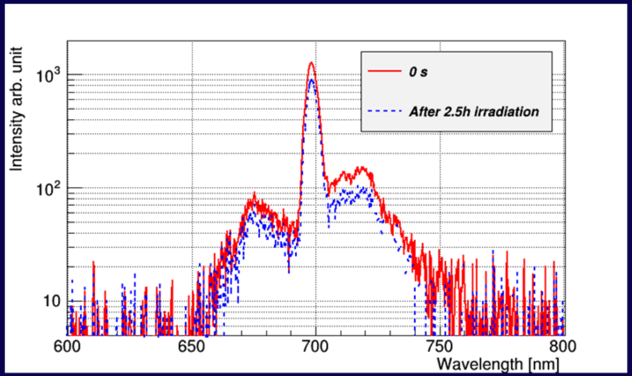
0 Gy　1 MGy　2 MGy

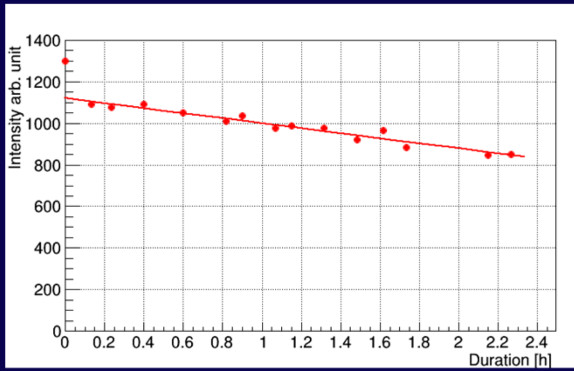
2D profile monitor

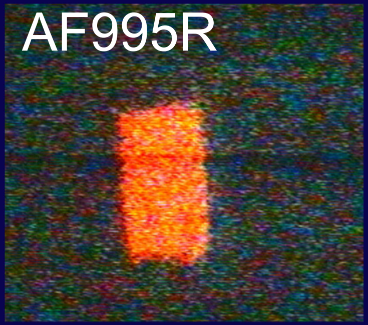


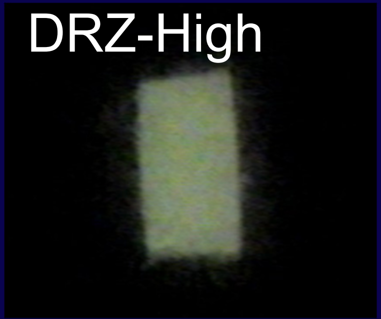
- Irradiation with Ar beam to perform efficiently
- Degradation light yield found at peak ~0.7 μm

Al_2O_3 + Cr 0.5%

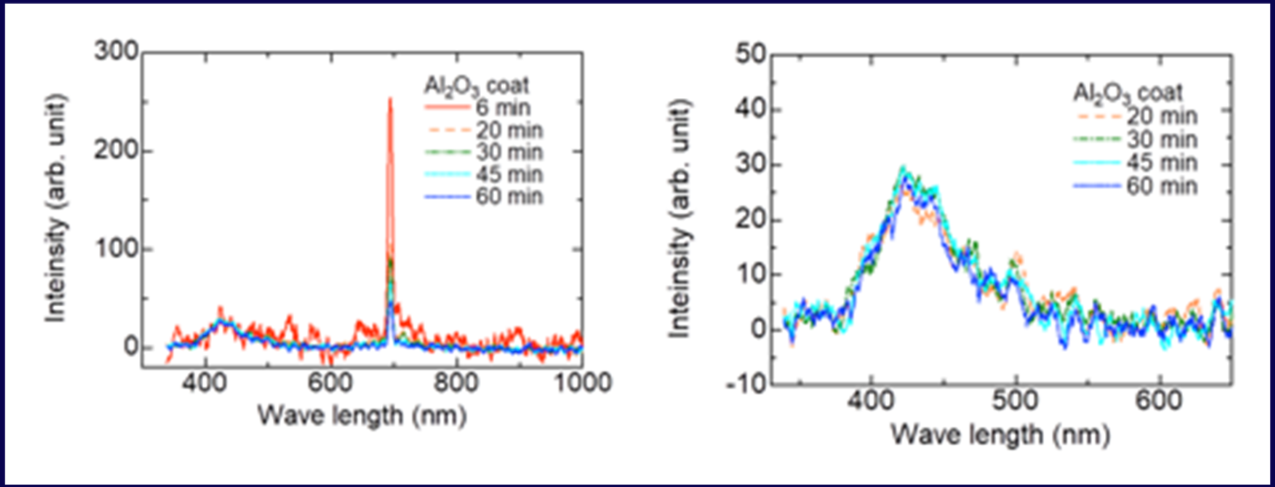








Al_2O_3 paint with low impurity: No degradation in short wavelength



Second target station for neutron and muon

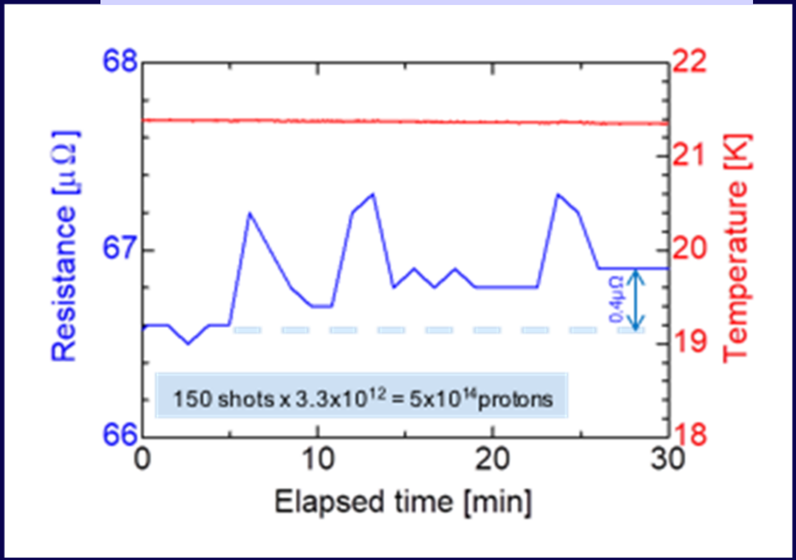
1st target ST (TS-1): 24 Hz: 1MW
2nd target ST (TS-2) 1Hz :   42kW (Designed to accept 1 MW)

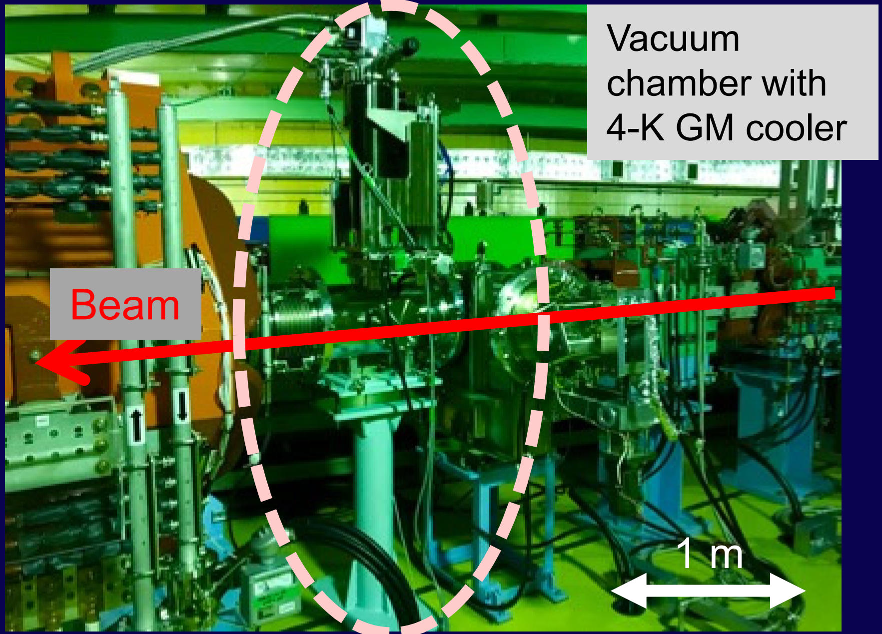
Since smaller target will be employed, higher current than TS1

Displacement cross-section

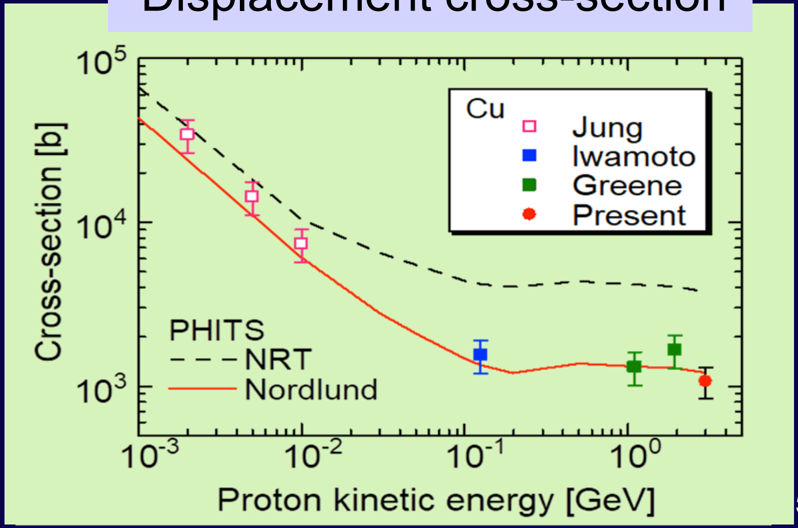
- Displacement per atom (DPA) is an index for lifetime estimation materials, however that cross-section has not been measured. (Y. Iwamoto TUP2WE03)
- Under cryogenic condition, the cross-section can be obtained by change of resistivity.
- Data giving the damage information for SC accelerators

Resistivity change of sample





Displacement cross-section



Summary

- Beam shaping system has been developed to mitigate current density on the target and can reduce by 30% from the linear-optics case.
- A tiny failure improves the safety of the accelerator drastically.
- Research and development for the robust beam profile monitor utilized at the ADS will continue.

Thank you